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A.S.E.

RADAR CAMOUFLAGE.

JTIA - 8069 Jan 1945

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Reference (a) [illegible] 16(S)16 February [illegible]

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Subject [illegible]

S-E-C-R-E-T.

F1 396B

JEIA
No. 7269

SUMMARY:

This report is of primary interest to OpNav, BuShips (Code 900), BuAer (RAE), BuOrd (ReAf) and N.R.L. It forwards a report prepared by the Admiralty Signal Establishment to examine theoretically the degree of screening which can be achieved by the absorption of the incident radiation. Added emphasis has been given to this problem as a result of recent reports of enemy use of radar camouflage.

Encl (A) (H.)1 copy of Admiralty Signal Establishment Report M.683, "Radar Camouflage," dated 16 January, 1945. Serial No. 24.

1. Arrangements have been made for the Admiralty and [illegible] to receive some "Harp" material, and joint discussions have been held with Lt. Cdr. Harvey [illegible], U.S.N.R.

2. Paragraph 2.4 of Enc. (A) refers to the effect of a film of sea water on the surface of the material, and it is considered that this can be serious. A dispatch has been sent to [illegible] (see Ref. (a)), requesting that trials be carried out in the [illegible] to determine this point, since the general belief voiced in the [illegible] [illegible] is that the effect is negligible.

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Y-7932

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RADAR CAMOUFLAGE.

SERIAL No. 24.

ADMIRALTY SIGNAL ESTABLISHMENT.

JANUARY 1945.

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RADAR CAMOUFLAGE

INTRODUCTION

Recent reports have pointed to the possibility that certain German naval craft, notably E boats, are being camouflaged against our radar of 10 cm. and 150 cm. wavelengths.

At the latter wavelength, a D.N.I. report on the interrogation of survivors of German E boats gives some information about steel netting with inserted elements (presumably resistances) said to have proved satisfactory at trials held in December, 1941. At 10 cm. no specific indication of the nature of camouflage is available.

The object of this report is to examine theoretically the degree of screening which can be achieved at the two frequencies mentioned, by the absorption of the incident radiation. An alternative method, in which the radiation is deflected by inclined screens, will be treated in a later report.

The report is in three sections.

In Section I the reduction of echo amplitude necessary to obtain results of operational value is considered.

Section II discusses theoretically the reduction of echo amplitude which can be achieved in certain ideal cases, and attempts to estimate the limitations imposed by practical difficulties connected with the irregular shape of targets to be screened.

In Section III the results of Section I and II are collated to give an estimate of the degree of screening attainable against certain general applications of radar.

I. REDUCTION OF ECHO AMPLITUDE REQUIRED

1. Variation of echo amplitude with range

1.1 The radiation field strength produced by a transmitting station in free space is inversely proportional to the distance, r, from the station. A target at this distance gives rise to a scattered wave of amplitude proportional to the incident field strength. The field strength of the scattered radiation at the transmitter is then inversely proportional to r^2. If the scattered field strength is reduced by a factor S by the method of screening adopted, the echo signal strength at the radar station is proportional to S/r^2.

The factor S so defined will be called the screening coefficient. It is equal to 0 for a perfectly screened target and to 1 for an unscreened target.

At limiting range for detection, r_o, the received field strength is equal to the minimum detectable field strength, E_o (say)

E_o is proportional to S/r_o^2

$\therefore$ r_o is proportional to $\sqrt{S}$

1.2 If the radar set and the highest point of the target are near the sea, the field strength of the radiation is inversely proportional to r^2 for large values of r. An argument similar to that in 1.1 gives for this case

r_o is proportional to $\sqrt[4]{S}$

Curves of [illegible] these two cases are given in figure 1. To red[illegible] to half the value for an unscreened targe[illegible] in the first case and S = 0.06 in the secon[illegible]

1.3 [illegible] field strength with distance assumed in 1.2 [illegible] earth and applies only when target and r[illegible] range of each other. Echo strength decreases rapidly as the target drops below the horizon, and the requirements on screening coefficient to produce a useful reduction in range are much more severe in cases where range on the unscreened target is limited by the horizon. No general law can be given for this case, but it will be shown that no useful screening can be achieved.

2. Classification of cases

Radar applications can be classified roughly as follows:-

2.1 Detection of surface targets from aircraft and of aircraft from surface targets in general follows the law of 1.1 (r_o is proportional to $\sqrt{S}$).

2.2 Detection of surface targets by surface vessels in general follows the law of 1.2 (r_o is proportional to $\sqrt[4]{S}$). A.S.V. and the detection of aircraft also come into this class when the target is below the elevation of the first maximum in the vertical coverage diagram of the set.

2.3 Detection of surface targets by modern Allied 10 cm. sets is usually in the class defined by 1.3.

3 Detection of small targets

One important case is excluded from the above discussion. Ability to detect small targets at short ranges by centimetre wave sets is limited by the presence of sea clutter. The intensity of sea clutter depends on the characteristics of the set, and on the state of the sea, but some targets of practical importance give signal/clutter ratios of 2 or 3 to 1 with existing sets in average conditions. If the echo amplitude can be reduced by this amount the target will not be detected at any range. In this connection it should be remembered that signal amplitude is proportional to S.

II METHODS OF CAMOUFLAGE AND VALUES OF SCREENING COEFFICIENT ATTAINABLE

Two methods of camouflage by absorption are considered, which appear to be practicable with present materials. Of these, the first is particularly applicable to metre wavelengths and in one form is the method developed by Dr. Moullin at Metropolitan Vickers. It is also probably the basis of the D.N.I. report referred to in the introduction. The second method is particularly applicable to centimetre wavelengths, and research on materials in connection with this method is being carried on in the U.S.A.

In both methods the incident radiation is absorbed in an absorbing element backed by a reflecting sheet. As the distance of the reflecting sheet from the absorbing element is the frequency critical part of this construction, it should be realised that the reflecting sheet is an essential part of the system, and that to hang the absorbing element haphazardly in front of the target would serve no useful purpose.

Methods of screening large areas for normal incidence are available in principle, which avoid this limitation, but even these would suffer from the other limitations discussed below, and they would require an extensive programme of material research to become practicable.

It would be possible to combine these two methods discussed to give protection at two widely separated wavelengths at the cost of some deterioration of screening at the shorter wavelength.

RESISTIVE SHEET WITH METAL BACKING

Plane infinite target normal incidence

A uniform film of surface resistance $120\pi = 377$ ohms per square, backed by a metal surface a distance L behind, is non-reflecting for radiations of normal incidence, and wavelengths λ given by $\lambda = 4L, 4L/3, 4L/5$, etc. Fig (2) curve (a) shows the screening coefficient of such a surface over a wave band, if L is taken such that the first zero reflection is at $\lambda = 150$ cm. (i.e. $L = 37.5$ cm.). The second zero reflection occurs at $\lambda = 50$ cm. but is considerably sharper than the first. It is unlikely that the same screen would be serviceable at both wavelengths.

Such a resistive film has been made by Metropolitan Vickers in a solid sheet, or it could be replaced by a construction consisting of a wire mesh with inserted resistances.

Taking the polarisation of the incident wave as horizontal, the screen will consist of an infinite number of infinitely long horizontal wires, equally spaced in the vertical plane, and with resistances inserted in the wires at short intervals.

If the direction of polarisation of the incident radiation is not known, the set will consist of both vertical and horizontal wires. The analysis is the same for each, as there is no mutual interference. In what follows we shall therefore consider only the horizontal polarisation.

The following notation is introduced

- d = vertical spacing of wires (mesh size)
- r = radius of wires
- L = spacing of screen from target
- R = effective surface resistance of the inserted resistances.

If the resistances are of value ρ , and are inserted at spacings D, then

$$R = \rho \frac{d}{D}$$

When the screen is a continuous surface, we require R = 377 ohms and $L = \lambda/4$. If these parameters are taken, we get the curve of Fig.2(a) in the example where r = 5/32" and d = 37.5 cm. The zero of screening coefficient at λ = 150 cm has risen to a minimum of about 0.25(field strength) whilst the screening coefficient at λ = 50 cm has risen to nearly 1 because of the inductance of the wires of the mesh.

By an alteration of parameters, the minimum can be decreased. Keeping the mesh and radius as in the above example, it can be reduced from 0.25 to 0.15 by taking R = 282 ohm and L = 50 cm. See Fig.2 (b).

If the mesh size or wire radius is altered, the minimum can be brought to zero by a suitable choice of parameters. Thus keeping d = 37.5 cm, and doubling r gives curve (a) of Fig. (3), with zero reflection at λ = 150 cm (R = 188 ohm, L = 56 cm). With r = 5/16" and d halved, the variation of screening coefficient becomes very similar to that of the continuous surface (Fig. 3(c) R = 366 ohm, L = 61.5 cm). The minimum in the neighbourhood of λ = 150 cm is broader than that of the larger mesh.

Summing up these results, it can be said that:-

(1) Closest spacing to the target and best results are obtained with continuous sheet.

(2) The smaller the mesh size, the broader the minima.

(3) The optimum values of L and R depend on the mesh size and wire radius.

(4) If the mesh is not too large, or wire radius too small, the reflection can be made zero at one wavelength.

(5) Absorption bands at higher harmonic frequencies are of very doubtful value.

[illegible].2 <u>Finite target. Normal incidence</u>

For an application of these results to small craft, the horizontal lengths of the wires can still be taken as infinite, as they are long compared with a wavelength, but the number of wires in the vertical plane is determined by the height of the boat.

It is very difficult to obtain theoretically the effect of the finite size of net, but some indication of what may be expected can be got by making certain simplifying assumptions. On these assumptions, the curves of Fig. 4 have been produced. Curves (a) and (c) are reproductions of Fig. 2(b) and 3(a), for comparison with curves (b) and (d) which show how the screening coefficient has altered as a result of the target being 7'6" high instead of infinity. The parameters R and L have not been altered. An alteration would reduce the minimum somewhat, but not to zero with this size of mesh and boat height. With a height of boat 12'6" the reflection can be brought to zero, the frequency variation being as in Fig. 5 (d = 37.5 cm, r = 5/16", L = 48 cm, R = 220 ohms).

A further limitation in the application of these curves is that in practice the mesh would not be in a constant field, since the electric field falls to zero at the surface of the water. The effect of this would probably be to increase the importance of the upper part of the net, and presumably the edge effect. Also, as the edge effect will be quite different for vertical wires, a change in polarisation would alter the screening coefficient of a net made of horizontal and vertical wires.

There seems to be no doubt that the edge effects are of considerable importance in determining the screening coefficient, especially when very small values are necessary. It seems unlikely that a value much lower than 0.1 could be obtained in practice, even if the parameters of the netting were determined experimentally for each surface, and this would involve far too much labour to be practicable.

Although the effects of finite size have been illustrated by examples assuming the use of netting, similar results would obtain with a continuous resistive sheet.

1.5 <u>Effect of oblique incidence</u>

Radiation obliquely incident on a target camouflaged for normal incidence, is not completely absorbed. Fig. 6 shows how the screening coefficient varies with angle of incidence, for an infinite target screened by a resistive surface $\lambda/4$ in front. It rises from zero at normal incidence to 0.06 at 20°, and to 1 at 90°. There is a slight but unimportant difference between polarisations parallel and perpendicular to the surface.

A similar curve would result, for angles of incidence less than about 30°, for a finite target and correctly dimensioned net. The main lobe of the reflected ray lies along the direction of the optically reflected ray, whilst side lobes occur back in the direction of the incident ray. These lobes, for small angles of incidence, are reduced by the screen in the same ratio as the main lobe, so that Fig. 6 can be taken as correctly representing the screening coefficient for angle of incidence up to about 30°. For greater angles, the screening coefficient rises, reaching 1 at 90°.

The properties of this type of screening have been considered with particular reference to wavelengths of the order of 150 cms. It could, in principle, be applied to centimetric waves, but the type of screening described in 2 below is more convenient.

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2 LOSSY DIELECTRIC WITH METAL BACKING

The form of absorber considered here is an absorbent layer mounted on the surface of the target. The combination is non-reflecting, for a given depth of layer, if the dielectric constant and the power factor of the material of the layer are correctly chosen. Absorbent materials of this type with dielectric constants between 100 and 5000 have been developed in U.S.A.

2.1 Plane infinite target Normal incidence.

For values of dielectric constant greater than 2, the sheet will be non-reflecting if the following conditions are satisfied.

$$L = \frac{\lambda}{4} \cdot \frac{1}{\sqrt{\varepsilon + 0.288}} \left(1 + \frac{0.119}{\varepsilon + 0.288}\right)$$

$$\tan\delta = \frac{60\,\lambda\,\sigma}{\varepsilon} = \frac{4}{\pi\varepsilon} \sqrt{\varepsilon + 0.288} \left(1 + \frac{0.419}{\varepsilon + 0.288}\right)$$

ε = dielectric constant

$\tan\delta$ = power factor

L = depth of material in cms.

σ = conductivity (cm ohm)$^{-1}$

λ = wavelength in cms.

Taking ε as an independent variable, Fig. 7 shows, for λ = 10 cm, the required value of L and $\tan\delta$, for perfect screening. For large values of ε, $L = \frac{\lambda}{4}\frac{1}{\sqrt{\varepsilon}}$ approximately

so that large dielectric constants are necessary if we wish to work with small thicknesses

Figs. 8-11 show the frequency variation of the screening coefficient for ε = 3, 6, 10 and 100, the correct value of L and σ being used The effect of a small alteration of L is also shown

The frequency response is quite sharp, and becomes sharper the larger ε Since a 1% change in depth has the effect of approximately shifting the position of zero screening by 1% in wavelength, it is obvious that the thickness must be accurate.

To give reasonable band width of screening from ship to ship it is necessary to use values of ε not greater than about 10. This means (see Fig 7) that considerations of weight prohibit the use of this method for wavelengths much greater than 10 cm. Higher dielectric constants could be used for ship to air screening.

As was the case with netting, the response at higher harmonic frequencies will probably be too unreliable for use.

2.2 Finite Target

At 10 cm wavelength the linear dimensions for which the effect of finite size of the target on the screening coefficient becomes important are 1/15 of those for which it becomes important at 1½ metres For this reason difficulties of screening the hulls of ships due to the effect of finite size do not arise.

2.3 Effect of oblique incidence

The effect of oblique incidence is very similar to that found for netting, and the remarks made earlier apply to dielectric sheets too. Fig.13 shows the reflection coefficient for $\epsilon = 3$, plotted against angle of incidence; the curve is similar to that for netting. As ϵ becomes larger - with depth and conductance changing accordingly - the reflection curve approximates $\tan^2 \theta/2$, which is also shown in the figure. There is not much difference between these curves.

2.4 Effect of a film of water

The effect of a film of sea water ($\epsilon = 80$) on the surface of a camouflage system, can be serious. Fig.12 shows how the screening coefficient of an otherwise perfect screen varies with thickness of film at $\lambda = 10$ cm. A film of thickness 0.02 mm increases the screening coefficient from 0 to 0.06. The effect for longer waves can be seen from the curve by increasing the scale of thickness of film as the wavelength. It is not negligible, even at metric wavelengths, but the netting described in 1 is free from this defect.

3. PRACTICAL LIMITATIONS

The types of reflection which together give an echo from a target, can be divided roughly into two categories

(a) specular reflection

(b) scattered radiation.

Specular reflection arises from large, nearly flat, surfaces, which are approximately perpendicular to the transmitter - target direction. Such surfaces are constituted from such parts of the ship as the hull. As already shown, these surfaces are amenable to camouflage.

Scattered radiation arises from reflections at small, or irregularly shaped objects, and from side radiations from reflections at larger surfaces (oblique incidence). It is not possible to reduce appreciably these radiations by absorption.

A ship's superstructure and masts cannot be camouflaged because of the effects of finite size (important even at centimetre wavelengths because of the irregularity of shape) and oblique incidence. Radar aerials will also contribute to the reflection.

It has been assumed so far that the surface of the target itself is the metal backing for the absorbing element. In cases in which the superstructure can be enclosed in or protected by a separate screen, the problem becomes easier. It seems unlikely that many cases will occur in which this can be done.

III CONCLUSIONS

1 Screening of surface vessels from low sited sets

1.1 Modern Allied radar detects all but the smallest ships when their superstructure first appears above the horizon. Since the reflection from the superstructure cannot be substantially reduced, screening of the rest of the ship cannot reduce the detection range appreciably

With smaller ships such as E boats, reflection from the superstructure is still appreciable at detection range, and it is very unlikely that this range could be reduced below three quarters of the normal value by the methods considered.

.2 For 1½ metre sets the superstructure and masts contribute most of the reflection at limiting range, because of the height of these parts. Screening against metre wave sets, therefore, also will not reduce the detection range appreciably.

.3 Ships with little superstructure or with a superstructure of regular shape, or in which it is possible to screen the superstructure by a "built out" screen, can probably be screened to some extent. Landing barges which are to be screened from observation from ahead, and submarines may be included in this class. It is unlikely that the detection range can be reduced below half the value for the unscreened target, and even this will not be attained when the range on the unscreened target is limited by the horizon.

.4 Targets which give very small echoes of strength not much greater than that of sea clutter are usually of fairly regular shape and are always small. Schnorkels and submarine periscopes are the outstanding examples of this class. Screening coefficients of about 0.3 should be obtainable with such targets which would increase considerably the difficulty of detection amid sea clutter. Centimetric wave sets only are relevant to this question.

2. Screening of surface targets from airborne sets

2.1 In detection of surface vessels from airborne sets it is possible that the hull of the ship contributes an appreciable part of the echo at limiting range. Whether or not this is so is determined by the characteristics of the set, and the height at which it is flown.

The question can be determined for a particular set from the variation of limiting range with height, and the operating wavelength. If the hull does contribute, the detection range can be reduced by screening. The limitation is that the range will not be reduced below that at which the superstructure alone can be detected. A reasonable estimate for this is half maximum range.

2.2 For the case described in III 1.3, the detection range from aircraft might be reduced to ½ of maximum. This is subject to the limitation that the aircraft does not get a direct view of the unscreened deck of the vessel.

3. Bandwidth

Even in the most favourable cases described above, the usefulness of the screening is limited by considerations of bandwidth. For the degree of screening which this report indicates is possible in practice, the useful bandwidth would be of the order of ± 10%.

It is possible to combine the methods described in II.2 and II.3 to give screening at two widely different wavelengths, for example [illegible] and [illegible].

4. <u>Screening on X and K Bands</u>.

Because of their greater size relative to the wavelength, it should be possible to screen more parts of the superstructure on X and K Bands, but the practical difficulties of maintaining a constant thickness of absorbent material, and the increased effect of a film of water make it doubtful whether better overall results would be achieved.

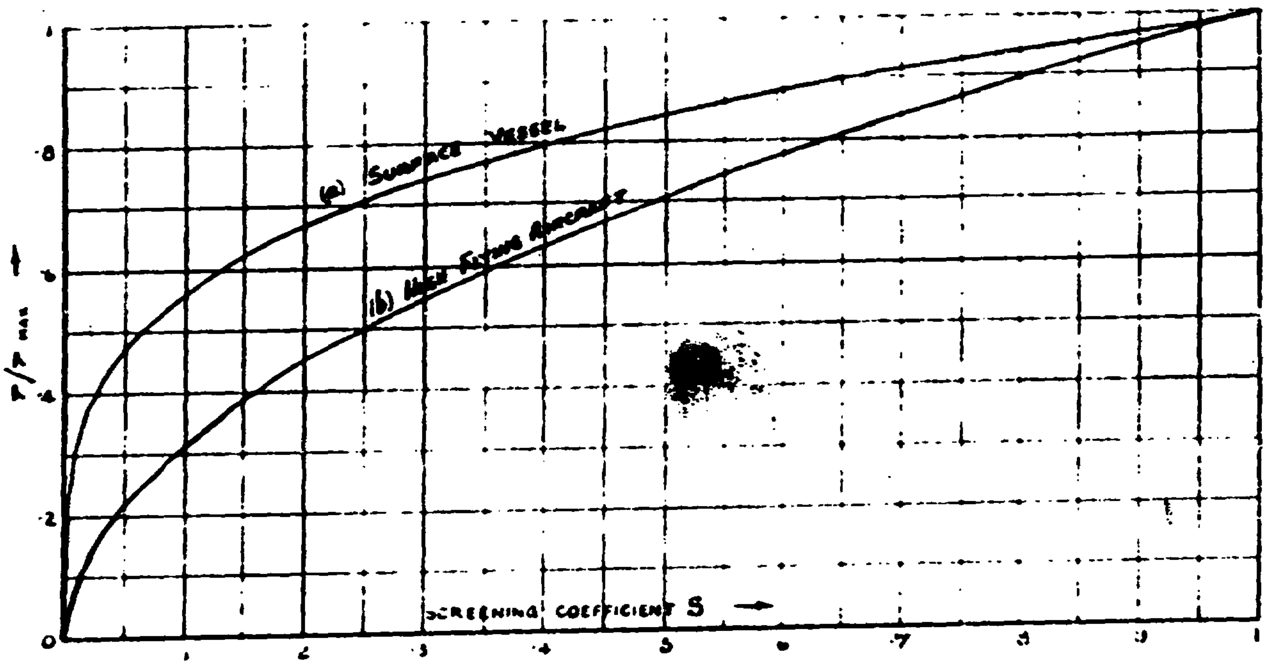
It should be stressed that it is not possible, by the methods considered, to screen a ship on more than one microwave band.

L. LEWIN.

-oOo-

FIG 1.

GRAPH SHOWING REDUCTION IN RANGE r REFERRED TO MAXIMUM RANGE r max. PLOTTED AGAINST SCREENING COEFFICIENT S



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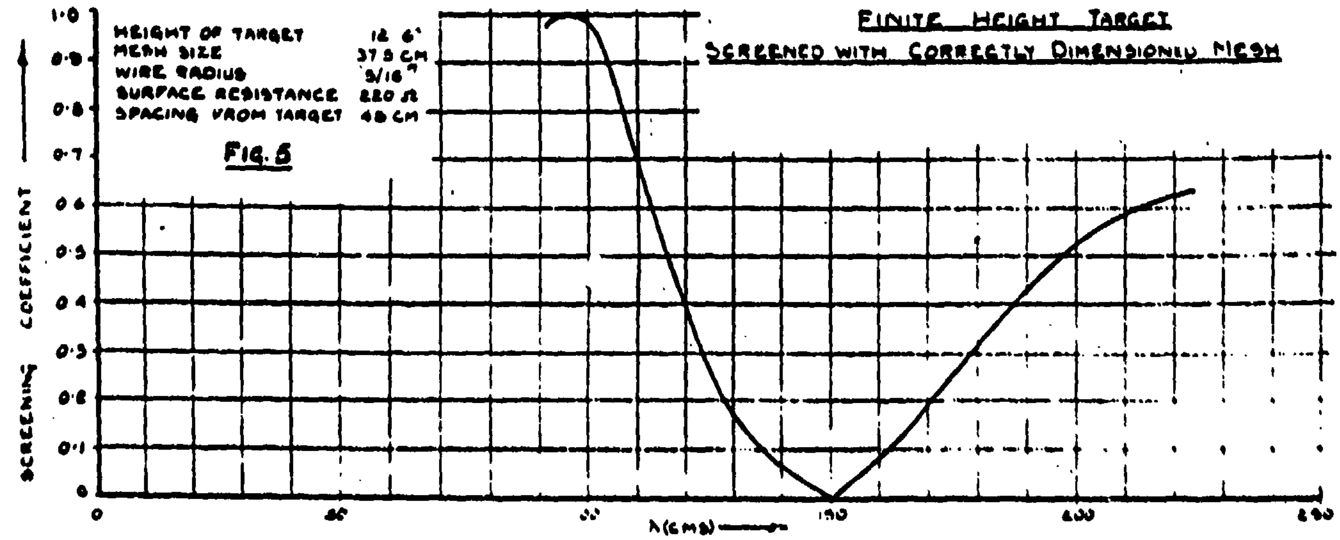
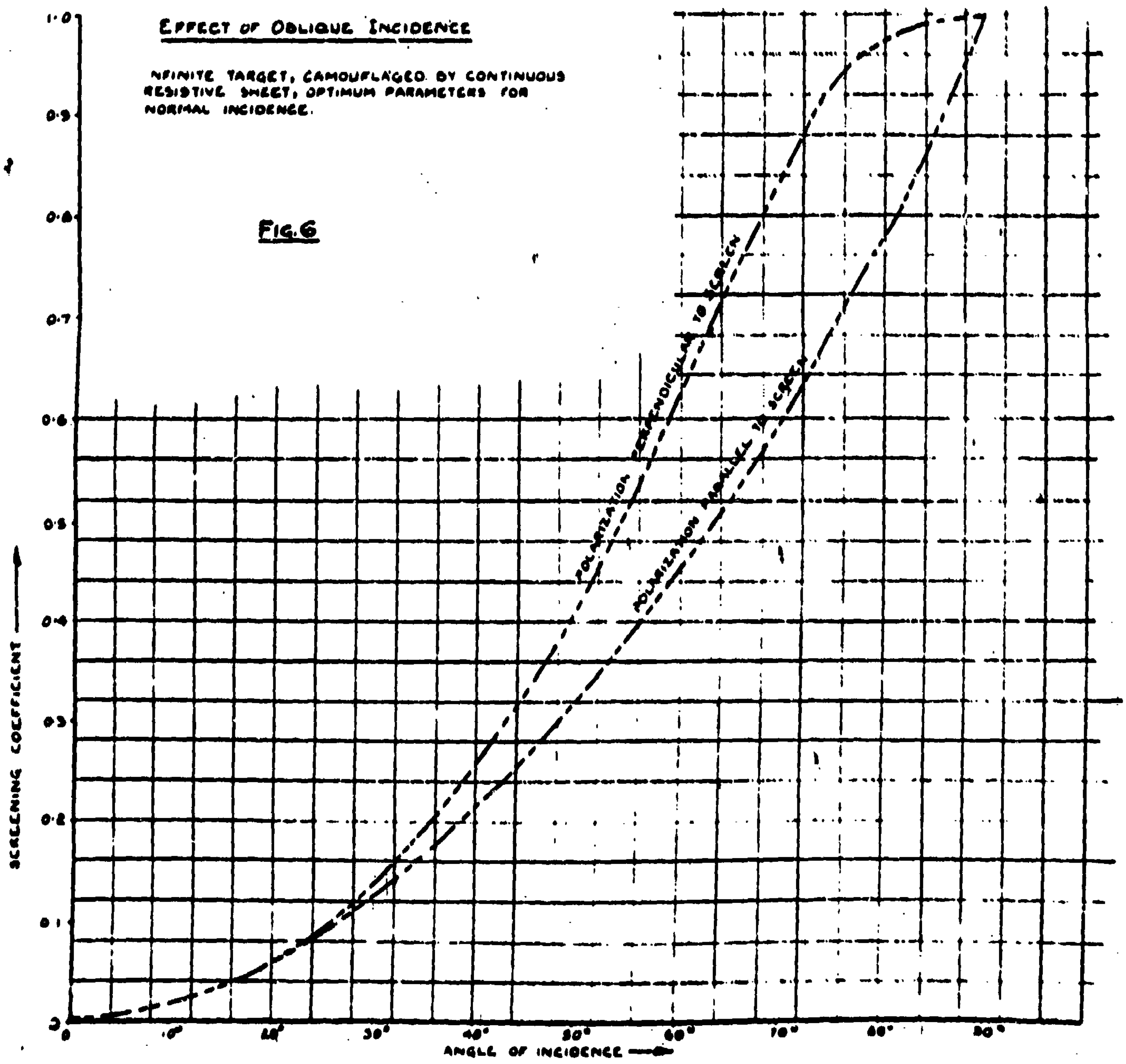


FINITE HEIGHT TARGET
SCREENED WITH CORRECTLY DIMENSIONED MESH
HEIGHT OF TARGET 12' 6"
MESH SIZE 37.5 CM
WIRE RADIUS 5/16"
SURFACE RESISTANCE 220 Ω
SPACING FROM TARGET 48 CM
SCREENING COEFFICIENT
λ (CMS)

FIG. 5



EFFECT OF OBLIQUE INCIDENCE
INFINITE TARGET, CAMOUFLAGED BY CONTINUOUS RESISTIVE SHEET, OPTIMUM PARAMETERS FOR NORMAL INCIDENCE.
POLARIZATION PERPENDICULAR TO SCREEN
POLARIZATION PARALLEL TO SCREEN
SCREENING COEFFICIENT
ANGLE OF INCIDENCE

FIG. 6

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DESIGN DATA FOR LOSSY DIELECTRIC SHEETING.

RELATION BETWEEN ε, TAN δ AND ℓ FOR ZERO REFLECTION AT λ = 10 CMS NORMAL INCIDENCE.

FIG. 7

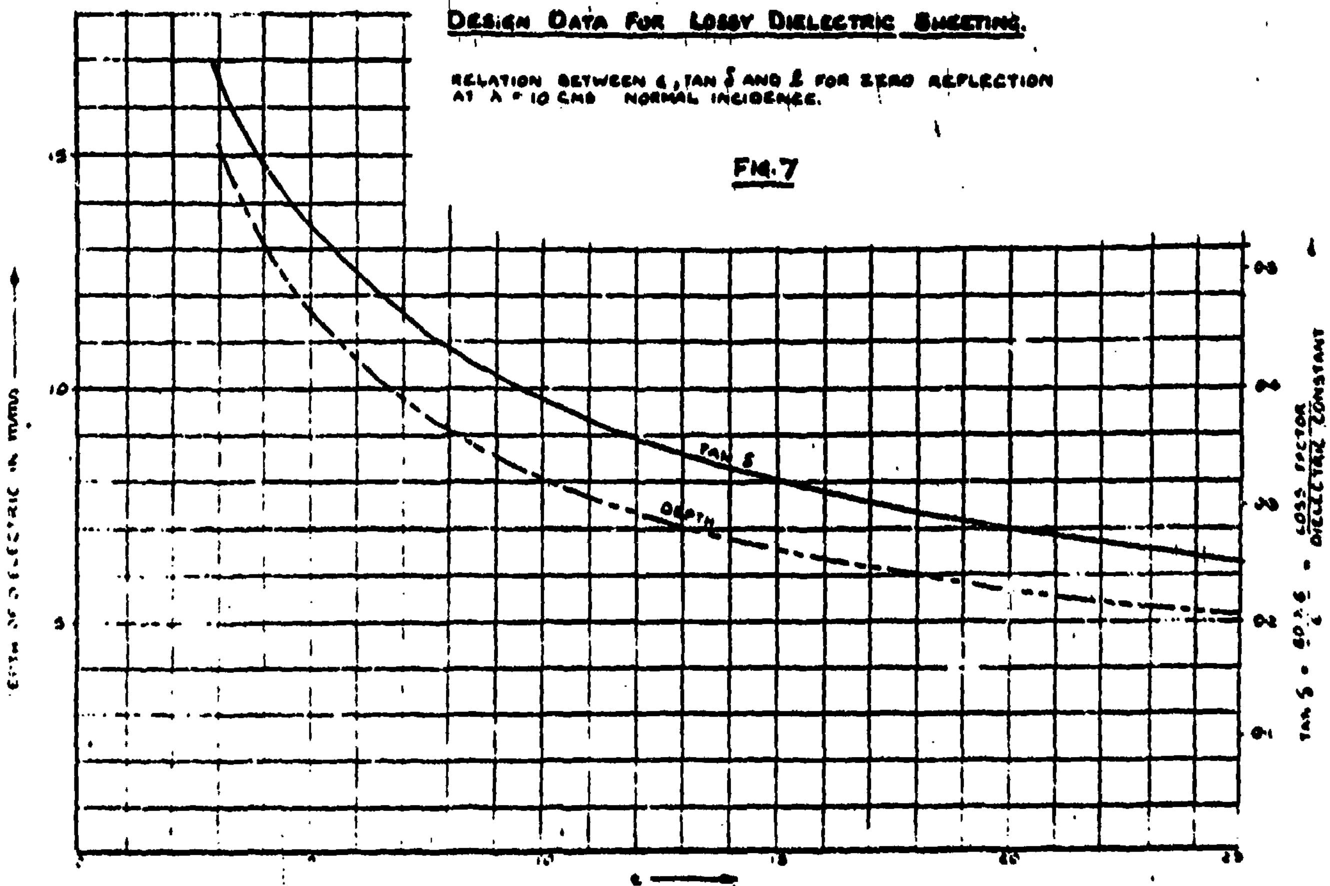
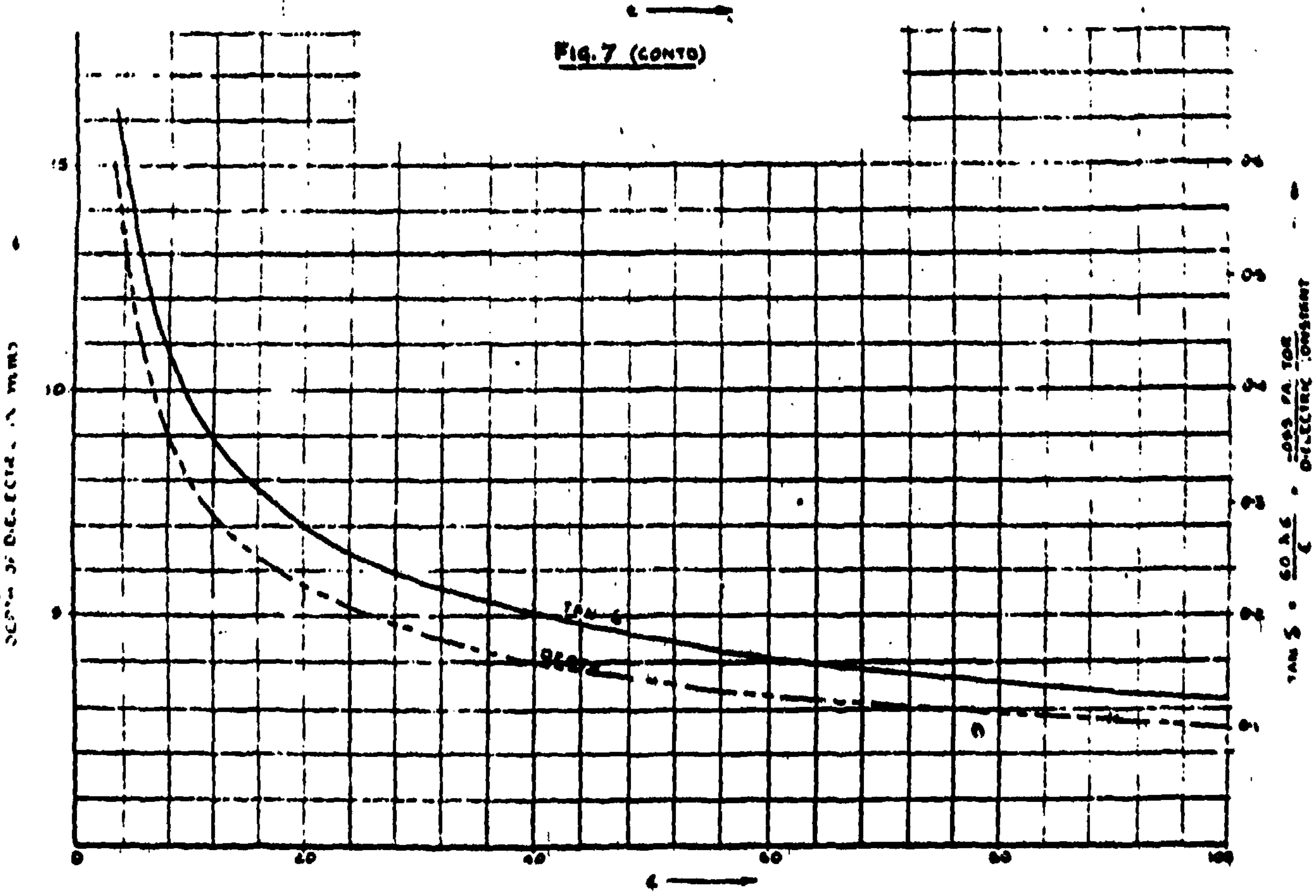


FIG. 7 (CONTD)



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15B

RESPONSE CURVES OF TARGET SHIELDED BY LOSSY DIELECTRIC SHEETING.

Fig. 8

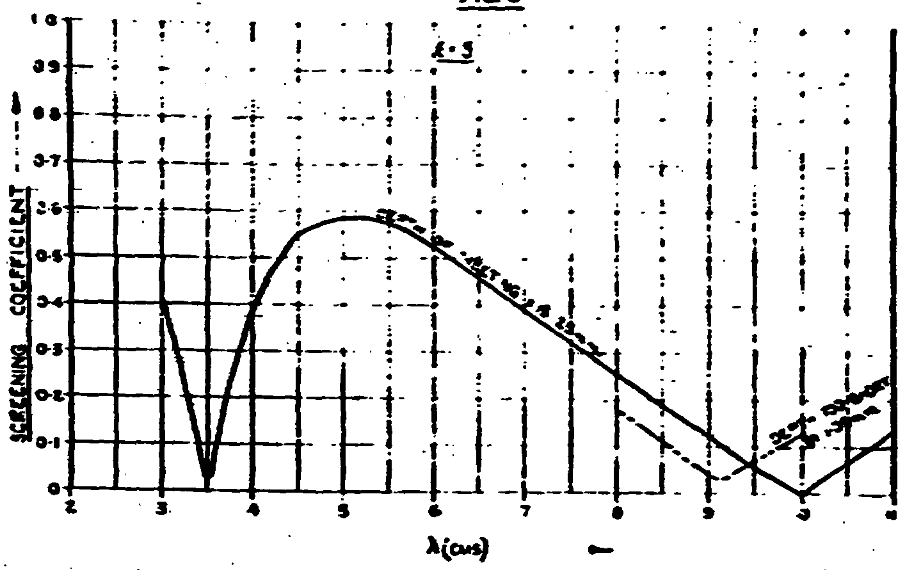


Fig. 9

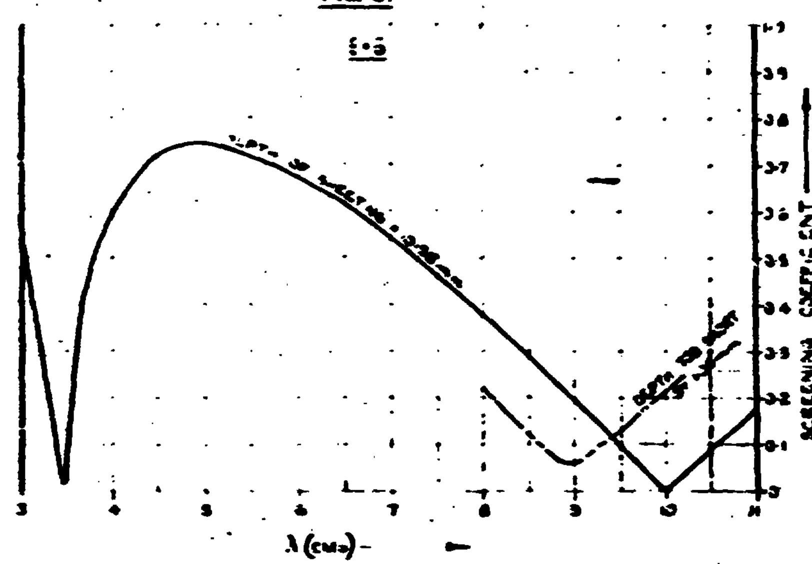


Fig. 10.

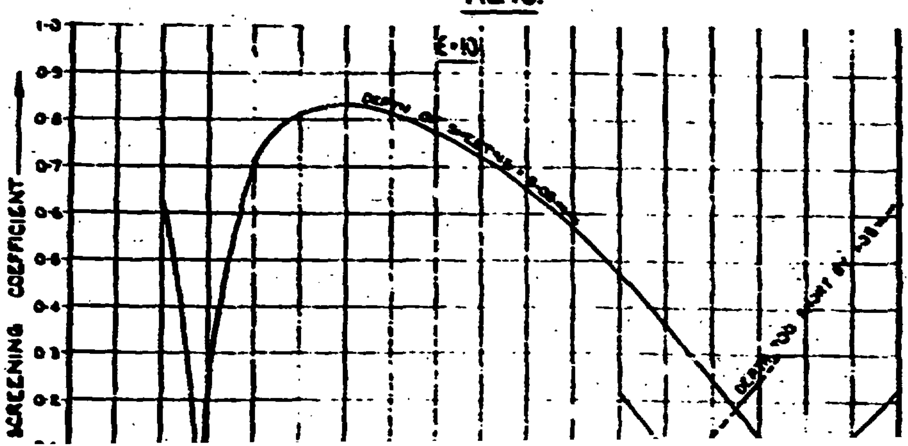
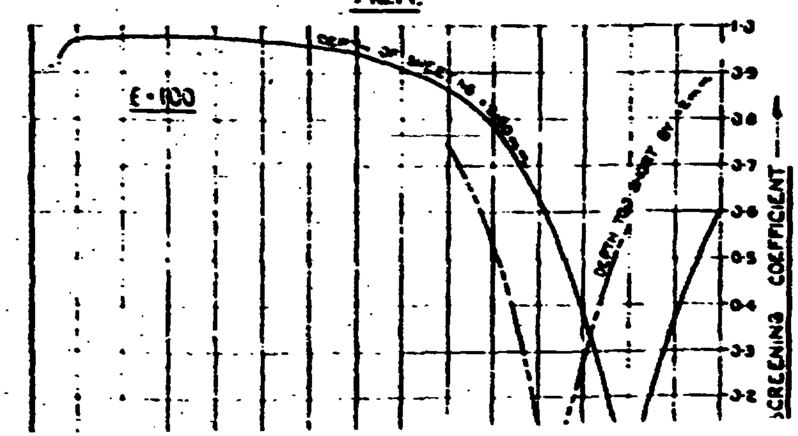
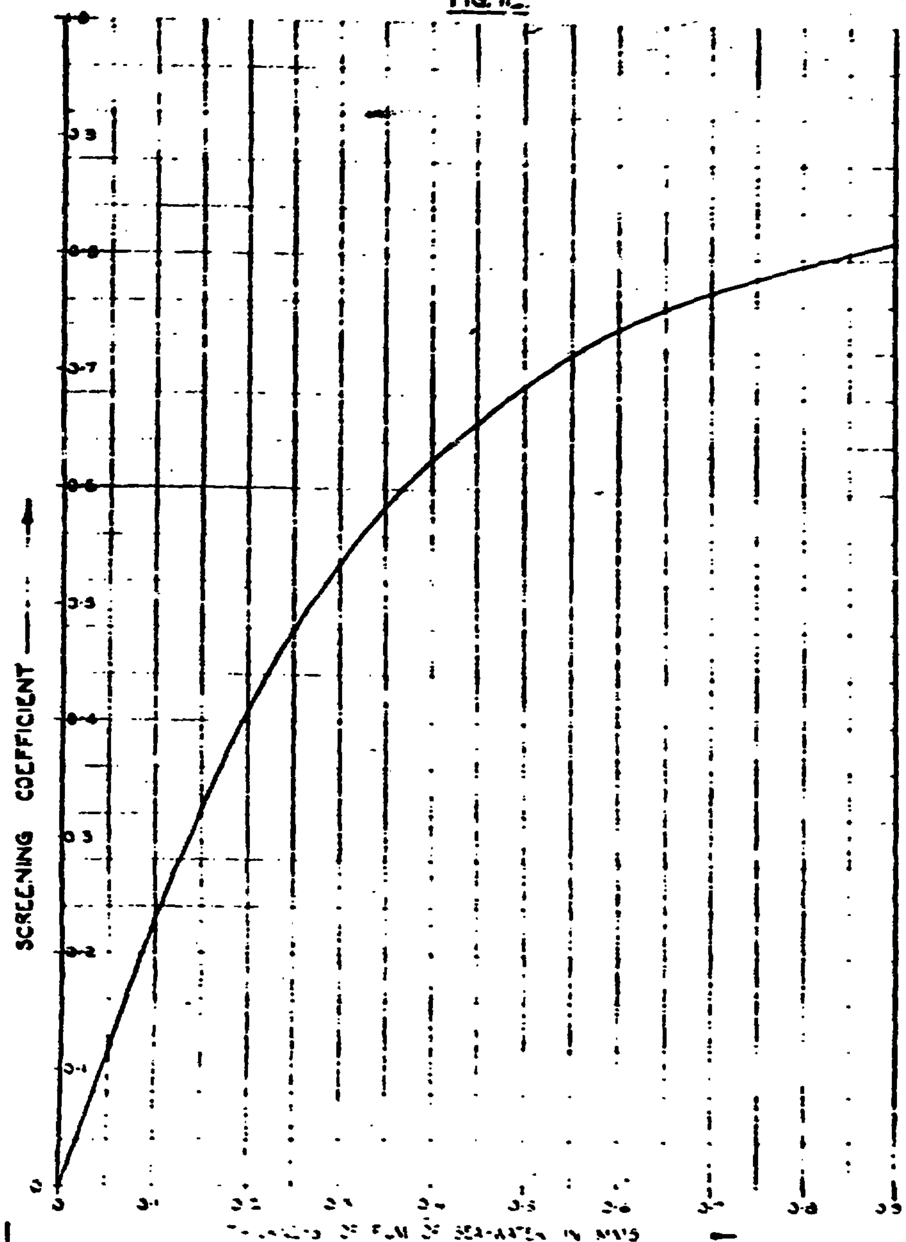


Fig. 11.



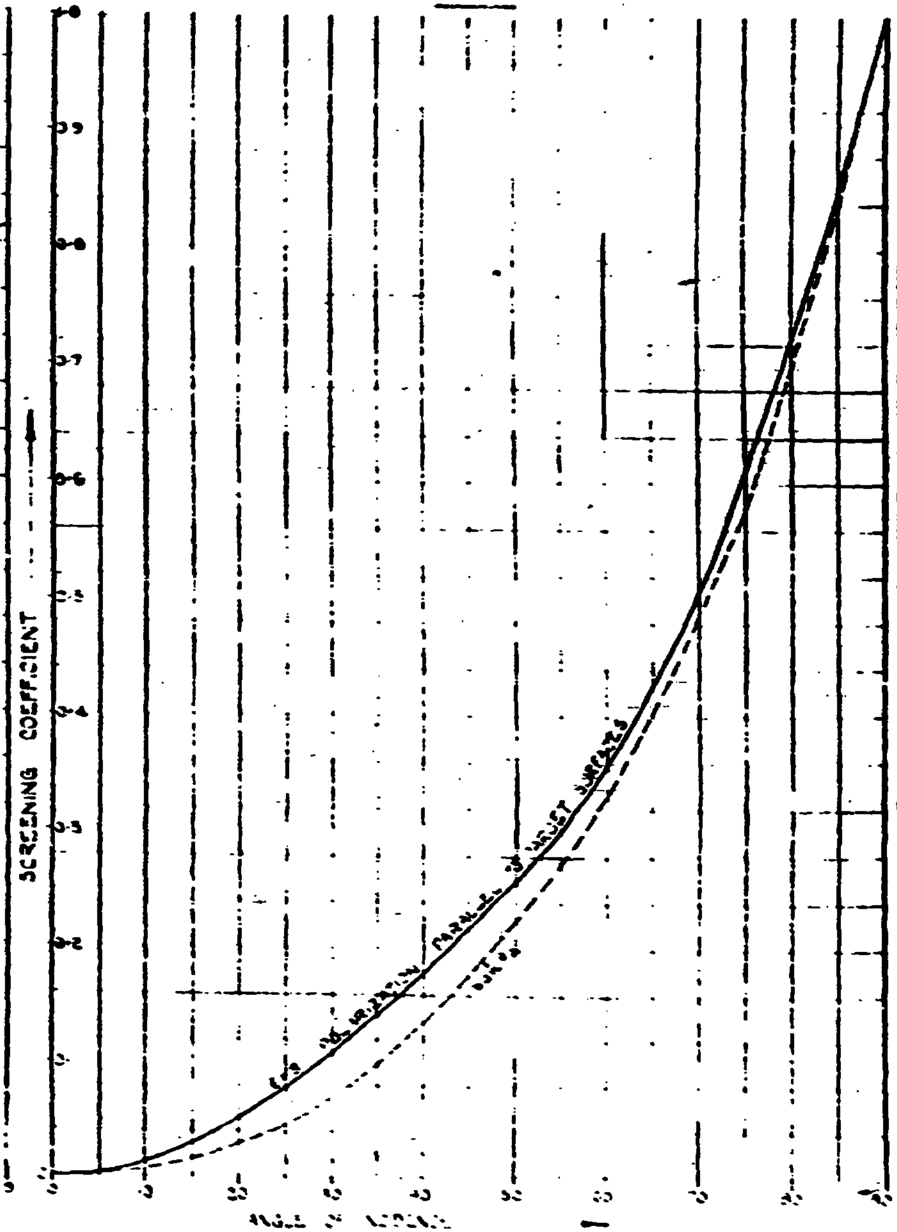
EFFECT OF SEA-WATER FILM ON CORRECTLY DIMENSIONED SHEETING.

Fig. 12.



EFFECT OF OBLIQUE INCIDENCE; SHEETING CORRECTLY DIMENSIONED FOR NORMAL INCIDENCE.

Fig. 13.



17B

ANTI-RADAR NETTING

FIG 2 EFFECT OF VARYING PARAMETERS

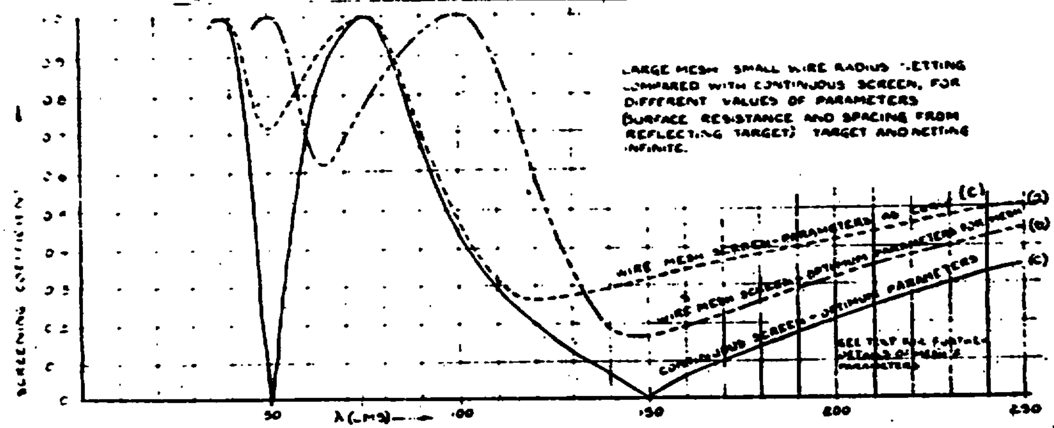


FIG 3 EFFECT OF VARYING MESH SIZE

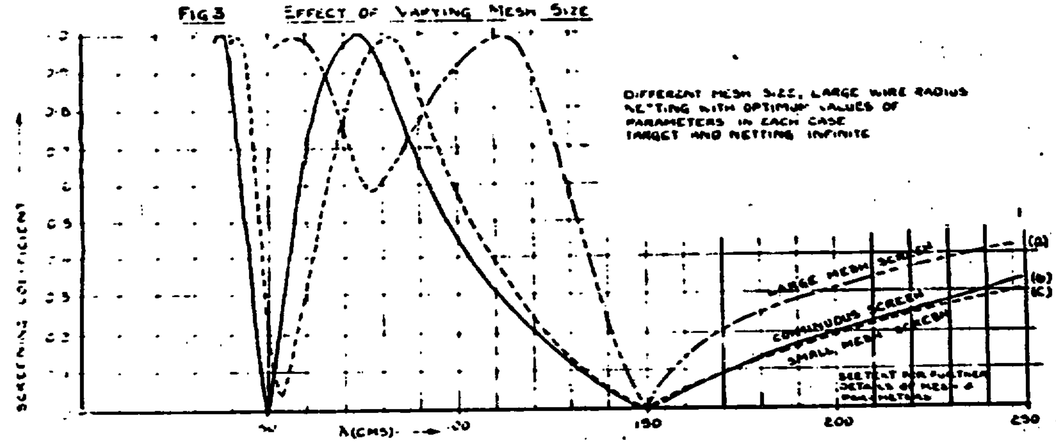
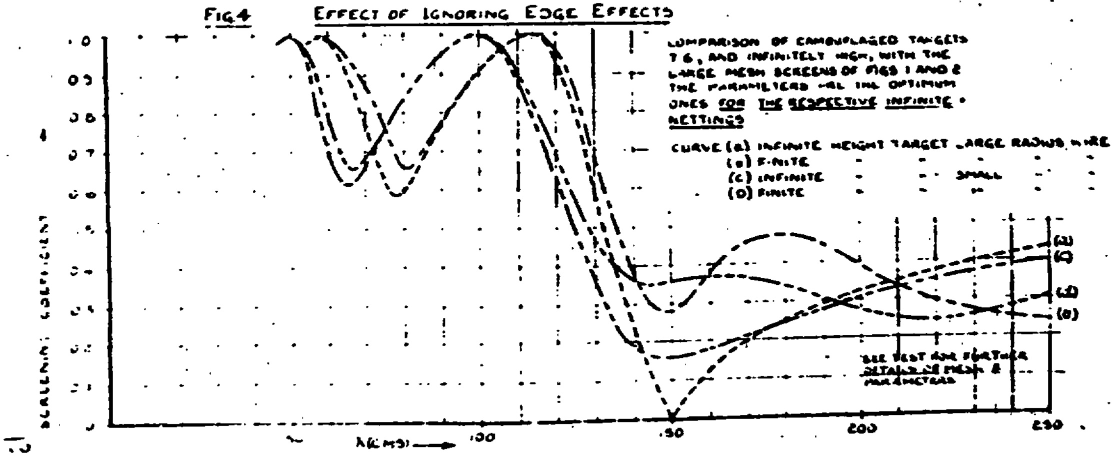


FIG 4 EFFECT OF IGNORING EDGE EFFECTS



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Ref: 98-M-0165/A1

[redacted]

This refers to our letter to you dated October 7, 1999, regarding your appeal to the Information Security Oversight Office for 14 documents previously requested under Mandatory Declassification Review procedures. One document (AD346727) was provided to you by our letter dated November 19, 1999.

The review of 11 British documents you requested is complete and there are no objections to release. Titles of these documents are contained on the enclosed sheet and a copy of each is enclosed. We will advise you as soon as the reviews of the remaining two documents are completed.

Per DoD letter, Please mark these 11 documents "available to the public."

Sincerely,

SIGNED

H. J. McIntyre
Director

AD-036 799
AD-044 992
AD-048 643
AD-057 151
AD-057 524
AD-057525
AD-057 526
AD-057 527
AD-122 495
AD-136 830
AD-139 544

I verified the docs could be marked available for public release via telecon with Pat Skinner, DoD Security Review, 695-9556/6428 on 21 Jan 2000,

Kelly Akers
DTIC-RS

1)

Received 2/8/2000